Conceptual Physics

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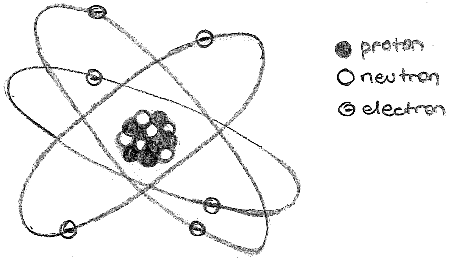
1. Structure and Properties of Matter
   - The basic building blocks of matter
   - The microworld $\leftrightharpoons$ macroworld connection
   - Photons
   - Burning

- All matter is composed of *molecules*
  and these molecules consist of one or more *atoms*
- Molecules retain characteristics of substance
- Molecules separate whereas atoms do not
  unless substance is one of the *elements*
- E.g. ☞ water molecules:
  hydrogen and oxygen separately have nothing to do with water
- Molecules of an element contain only one kind of atom
  e.g. ☞ hydrogen, oxygen, uranium, iron
- There are about 100 elements
  and therefore 100 different kinds of atoms
- Substances which are not elements are called compounds
  at present we know of about one million compounds

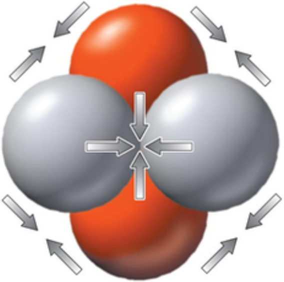
- Between 1900 and 1932 ☞ we essentially answered question: "What are atoms themselves made off?"
- 99.97% of atom mass is concentrated in *nucleus* at its center consisting of two kinds of heavy particles (*protons* and *neutrons*)
- Other 0.03% of mass consists of very light *electrons* which buzz around in fixed orbits very far from nucleus

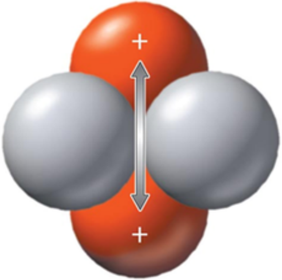


- Scale of atom is such that if nucleus were size of golfball electron orbits would be at a distance of 1/2 mile

- Besides mass ☞ electron and proton have electric charge
- Although electron is $2,000$ times lighter than proton
  it has same charge as proton
- More precisely ☞ it has an equal and opposite charge
- Neutron is *neutral* ☞ it has no charge
- Recall ☞ electric charges come in two kinds: $+$ and $-$
- Like charges repel one another whereas opposite charges attract
- Forces become much stronger when charges are closed together

- Electrons are held in orbit by electrical attraction of protons
- Atom is neutral ☞ always equal numbers of electrons and protons
- Nuclear force
  - Reason protons in nucleus do not fly appart due to their strong electrical repulsion
  - Much stronger attractive force between neutrons and protons (a hundred times as strong) comes into play at these small distances





- We describe atomic structure in terms of:
  1. atomic number Z ☞ number of protons inside nucleus
  2. baryon number A ☞ number of nucleons N inside nucleus
- Nuclei of all atoms of particular element
  contain same number of protons
  but often contain different numbers of neutrons
- Nuclei that are related in this way are called isotopes
- For isotope with baryon number A of element with symbol X
  it is common writing $^{A}_{Z}$X
- E.g. ☞ when we write $^{238}_{92}$U we mean isotope of uranium
  which has a total of 238 neutrons plus protons and 92 protons
  (How many neutrons?)

Relative Atomic Mass Scale

What is the Relative Atomic Mass Scale (^{12}Carbon Scale)?

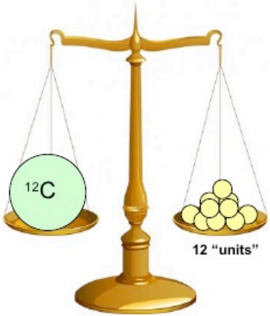
- masses of atoms are expressed relative to the mass of a Carbon-12 atom.

Why is there a need for the scale?

- atoms are too small to be weighed directly.
- inconvenient to express masses of atoms in terms of kg.

So what does it imply?

- 1 atom of ^{12}C = 12
- 1/12 the mass of a ^{12}C atom = 1



Note: Relative atomic masses have no units (dimensionless) since they are relative to the arbitrary standard (i.e. ratio).
However, in more advanced texts, relative masses are represented in terms of atomic mass units (u)

microworld	$\longrightarrow$	macroworld
atoms & molecules		grams

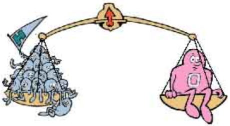
Atomic mass $\Rightarrow$ mass of an atom in atomic mass units (u)

> By definition:
> 1 atom ^{12}C "weighs" 12 u

On this scale

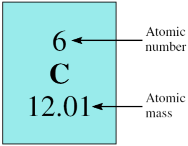
^{1}H = 1.008 u

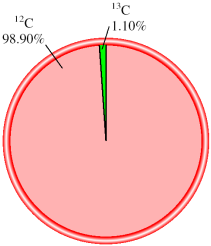
^{16}O = 16.00 u



average atomic mass

weighted average of all of naturally occurring isotopes of element





Naturally occurring lithium is:
7.42% ^{6}Li (6.015 u)
92.58% ^{7}Li (7.016 u)

Average atomic mass of lithium:

$$\frac{7.42 \times 6.015 + 92.58 \times 7.016}{100} = 6.941\,\mathrm{u}$$

1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8	9 8B	10	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1 H Hydrogen 1.008																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 19.00	10 Ne Neon 20.18
11 Na Sodium 22.99	12 Mg Magnesium 24.31											13 Al Aluminum 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.07	17 Cl Chlorine 35.45	18 Ar Argon 39.95
19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.88	23 V Vanadium 50.94	24 Cr Chromium 52.00	25 Mn Manganese 54.94	26 Fe Iron 55.85	27 Co Cobalt 58.93	28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.39	31 Ga Gallium 69.72	32 Ge Germanium 72.59	33 As Arsenic 74.92	34 Se Selenium 78.96	35 Br Bromine 79.90	36 Kr Krypton 83.80
37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.1	45 Rh Rhodium 102.9	46 Pd Palladium 106.4	47 Ag Silver 107.9	48 Cd Cadmium 112.4	49 In Indium 114.8	50 Sn Tin 118.7	51 Sb Antimony 121.8	52 Te Tellurium 127.6	53 I Iodine 126.9	54 Xe Xenon 131.3
55 Cs Cesium 132.9	56 Ba Barium 137.3	57 La Lanthanum 138.9	72 Hf Hafnium 178.5	73 Ta Tantalum 180.9	74 W Tungsten 183.9	75 Re Rhenium 186.2	76 Os Osmium 190.2	77 Ir Iridium 192.2	78 Pt Platinum 195.1	79 Au Gold 197.0	80 Hg Mercury 200.6	81 Tl Thallium 204.4	82 Pb Lead 207.2	83 Bi Bismuth 209.0	84 Po Polonium (210)	85 At Astatine (210)	86 Rn Radon (222)
87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium (257)	105 Db Dubnium (260)	106 Sg Seaborgium (263)	107 Bh Bohrium (262)	108 Hs Hassium (265)	109 Mt Meitnerium (266)	110 Ds Darmstadtium (269)	111 Rg Roentgenium (272)	112	113	114	115	116	(117)	118

10 Ne Neon 20.18 — Atomic number; Atomic mass

Average atomic mass (6.941)

58 Ce Cerium 140.1	59 Pr Praseodymium 140.9	60 Nd Neodymium 144.2	61 Pm Promethium (147)	62 Sm Samarium 150.4	63 Eu Europium 152.0	64 Gd Gadolinium 157.3	65 Tb Terbium 158.9	66 Dy Dysprosium 162.5	67 Ho Holmium 164.9	68 Er Erbium 167.3	69 Tm Thulium 168.9	70 Yb Ytterbium 173.0	71 Lu Lutetium 175.0
90 Th Thorium 232.0	91 Pa Protactinium (231)	92 U Uranium 238.0	93 Np Neptunium (237)	94 Pu Plutonium (242)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (249)	99 Es Einsteinium (254)	100 Fm Fermium (253)	101 Md Mendelevium (256)	102 No Nobelium (254)	103 Lr Lawrencium (257)

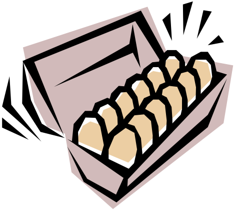
Metals

Metalloids

Nonmetals

Mole (mol): A unit to count numbers of particles

Dozen = 12



Pair = 2

Mole ☛ amount of a substance that contains as many elementary entities as there are atoms in exactly 12.00 grams of ^{12}C

$$1 \text{ mol} = N_A = 6.022 \times 10^{23}$$

N_A ☛ Avogadro's number

Molar mass is the mass of 1 mole of eggs / shoes / marbles / atoms in grams

1 mole ^{12}C atoms = 6.022 x 10^{23} atoms = 12.00 g

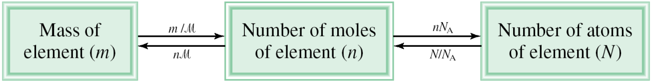
1 ^{12}C atom = 12.00 u

1 mole ^{12}C atoms = 12.00 g ^{12}C

1 mole lithium atoms = 6.941 g of Li

For any element
atomic mass (u) = molar mass (grams)

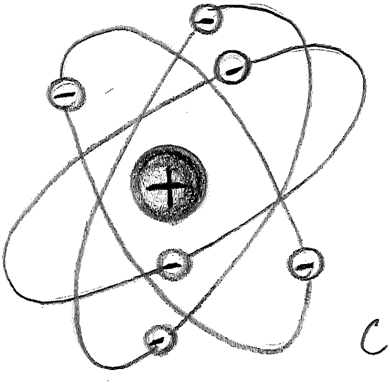
1 u = 1.66 x 10^{-24} g or 1 g = 6.022 x 10^{23} u

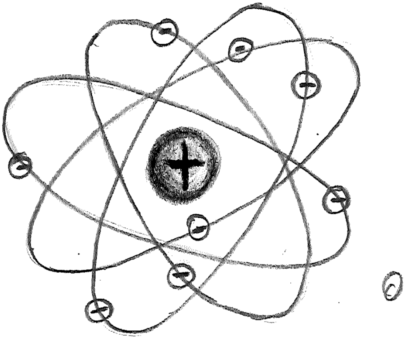


$\mathcal{M}$ = molar mass in g/mol

N_A = Avogadro's number

Two atoms of C and O combine to form a CO molecule as follows

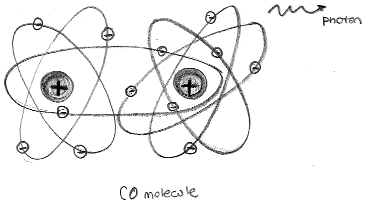




- In one way or another (which we will discuss soon)
  C and O atoms are driven up against one another
- Negative electrons repel each other and atoms fly appart
- But once in a while pair of atoms come together so hard
  that electrons are driven past each other
- Negative C electrons get far enough past negative O electrons
  and begin to experience *attractive force of positive O nucleus*
- Same history for oxygen electrons
- When this happens ☞ C and O combine into stable CO molecule

As atoms snap together ☞ something very important happens:

- Small packet of energy (called photon) is emitted
  (sort of like when 2 magnets snap together little heat is generated)
- For each molecule of CO formed ☞ a photon is emitted
  and all photons have same energy
- So every time 3 grams of C combines with 4 grams of O
  same amount of energy (6 Cal) is released
  (in form of million billion billion photons)
- Reason C and O always combine in proportions 3-g-C to 4-g-O
  is that 3 g of C contain same number of atoms as 4 g of O
  and atoms just combine one-to-one



Now we come to a crucial consideration ☞ *chain reaction*

- Let us suppose following two considerations are fulfilled:
  1. There are many C and O molecules together
  2. C and O molecules are well interspersed
- Then ☞ γ originating in combination of one pair of C and O has good chance of hitting another C (or O) and driving it with enough force to combine again with O (or C)
- Combination will go on without outside energy so long as there are enough C and O atoms close together and they are interspersed enough [conditions (1) and (2)]
- This is what we call *burning*
- Condition (1) can be translated to mean "we need enough fuel"
- Condition (2) ☞ "give the fire some air!"

How do we *ignite* the reaction?

- We must agitate C-O mixture so that C's really slam into O's overcoming repulsion of outer electrons
- Agitating group of molecules to larger average velocity is definition of raising temperature of group
- We can raise temperature of mixture by:
  1. introducing another source of photons (a light match)
  2. physically agitating the C's (friction)

  e.g. ☞ as rocket nose cone burns when it rushes through air

Where does the photon come from?

- Unfortunately ☞ complete revelation of these secrets
  would require you to take graduate physics course
- At this point we can simply provide following explanation
- Photon does not exist in atoms before it appears
- But when it appears ☞ something else does disappear: *mass*
- Mass of CO molecule is less than sum of C and O atom masses
- Einstein discovered relation between: { photon energy E / disappearing mass m

$$E = mc^2$$

c ☞ speed of light

- In energy units you have learned that
  appearance of 2 Cal of energy in photons
  is associated with disappearance of 10^{-10} g of mass
- Roughly speaking ☞ 10^{-8}-th of mass of fuel burned disappears